A Virtual Window Using Curtains and Image Projection*

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Abstract
In this paper, we propose a system that presents a virtual window using curtains and projection. A screen and curtains are installed on the wall, and images are projected as they are opened and closed. By using curtains, which are commonly used in life, this system replaces the role of windows in everyday life by projecting images naturally onto our living environment. We propose applications that focus on spatial presentations and communication provided by the window and discuss there potential of this system.

Keywords
Virtual Window, Curtain, Projector

1. Introduction

The living environment is important for people to lead comfortable daily lives. For a more comfortable life, it is desirable to live in a place with sufficient space, windows connecting the inside to the outside world, and no feeling of being blocked in. However, because of design problems caused by the density of buildings or financial issues, many people live in places with little space, in underground places with no windows, or in small rooms.

Solutions to these problems include to arrange furniture to improve openness, or the use of mirrors in interior design to create the impression of ampler. However, these spatial presentations lack flexibility and ease of use. It requires personal sense and knowledge to make an effective interior design. Since mirrors reflect what actually exists in the environment, skill is required to successfully create a spatial presentation with a sense of openness. Therefore, neither approach can easily eliminate the sense of being blocked.

Therefore, this study proposes a method of creating a virtual window using curtains and projection to produce a spatial presentation. A screen and curtains are installed on a wall, and images are projected as the curtains are opened and closed. Using a projector, the appearance the window and the size of the window can easily be changed, making this system more flexible. Moreover, using curtains, which are commonly used everyday items, the window is presented in such a way that it blends in with the living environment. Furthermore, the presence

Figure 1: Appearance of the projected window.

of the curtains gives depth to the flat projected image, and makes the system three-dimensional.

This virtual window substitutes for the window's original role of connecting to the outside world, presenting information and connecting to the space behind it, thus producing a spatial presentation. Once the position of the curtains and screen for the system is determined, the projector, PC, and webcam necessary for projection can be installed in any position, provided that simple conditions are satisfied. This makes it easy to design the environment in which the system is used.

2. Related Work

2.1. Presenting information using everyday items

Squama [1] is a programmable physical window or wall that can independently control the visibility of its elemental small square tiles. Atmoph Window is a display in the shape of a window and it provides the sound and the site [2]. Peek-A-Drawer [3] is a new communication device that uses furniture to support lightweight commu-

nication between people, which provides virtual shared drawers that connect family members who are located at a distance. Homma et al. proposed a method of presenting information using a shade and windows as screens, which can be projected from inside a room to create a display that can be seen from both inside and outside [4]. Projection BLIND is a blind that can be used as a screen for projected images, and can switch between the roles of a screen and curtains [5]. Mizuno et al. proposed an interactive system that responds to the viewer's movements using a projector to project images onto shoji screens in historical Japanese houses [6]. This research also uses curtains to present a window that can be manipulated by the user using everyday movements.

2.2. Methods focused on the role of curtains

There are methods that focus on the role of curtains in daily life. Tsuchida et al. propose a practice-support system for performing the formation using the two-axis movable curtain rail, whose movement direction does not drift and the material used for projection is soft [7]. Coehlo et al. describe Shutters: a curtain composed of actuated louvers that can be individually addressed for precise control of ventilation, daylight incidence and information display [8]. Smooth curtain [9] is a remote communication system that allows direct and ambient communication to be flexibly adjusted through intuitive operation by opening and closing the curtains. Smart curtain [10] is an interactive display in a living space projected onto a curtain. It can display images over a large area while maintaining the role of a curtain as a boundary between the inside and the outside, and it is characterized by its ability to detect the surrounding environment and the opening and closing of the fabric, and to perform context-sensitive actions. This research proposes an application that takes into account the role of the window as well.

3. Methods

In this research, a screen and curtains are set up against an empty wall, and a projector is used to project images onto the open areas of the curtains, presenting the entire system as a window. The projected area changes according to the opening and closing of the curtains.

3.1. System configuration

The system consists of a screen, curtains, a webcam, a PC, and a projector. Figure 2 shows an overview of the system. A camera connected to a PC captures images of curtains placed over the screen and transmits them
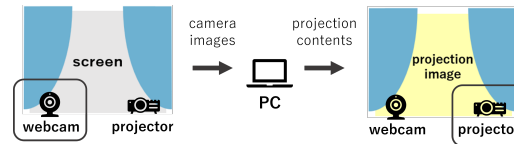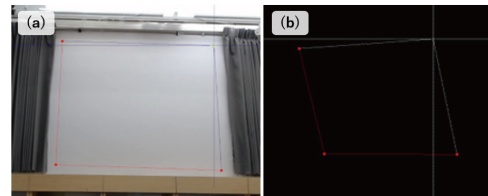

Figure 2: System configuration.

Figure 3: User interfaces for the camera and projection images. (a) extracting the screen area from the camera image; (b) determining the position of the projection.

to the PC. First, the screen area is extracted by the PC. Next, the open area of the curtain is calculated based on the extracted screen image. Finally, the PC creates an image or a video to be projected onto the screen area. The image is transferred to a projector, which projects it only between the left and right curtains.

Python was used for image processing on the PC, and the system was implemented mainly using OpenCV. The webcam was a Logitech C920HD. The projector was an EPSON EB-1795F, and the PC was an ASUS ExpertBook B9 B9450FA .

3.2. Software

3.2.1. Calculate the opening area of the curtains

The background subtraction method was used to calculate the open area of the curtains from the screen image acquired by the camera. The background image taken at first is an image of the screen without curtains, and the input image is an image of the curtains on the screen. The luminance difference between these images is compared to compute the areas where the curtains are open. The final binary image is used as a mask image and is combined with the image of the window to create the projected image. This research used a gray curtain and a white screen.

3.2.2. Camera image processing

The system can be used if the entire screen area is included in the webcam's angle of view. Only the screen area to be projected is extracted from the camera image. The image of the extracted screen area is transformed using projective transformation and treated as if it were
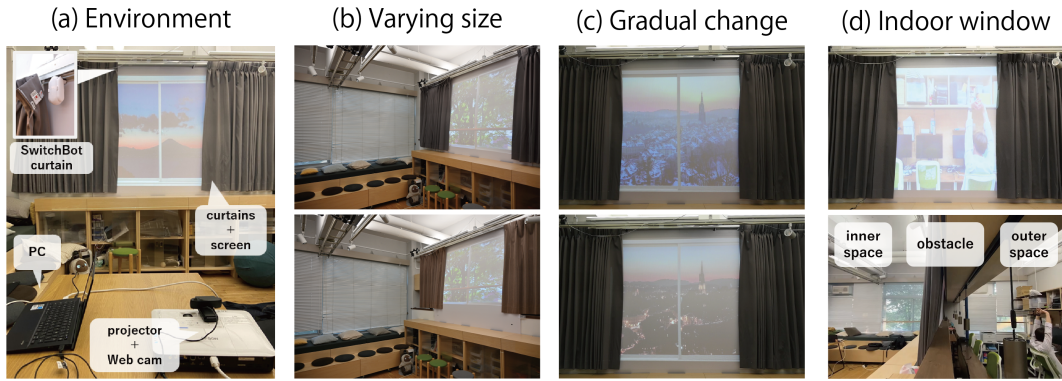
Figure 4: Implementation environment and apprications. (a)Implementation environment; (b)Windows of varying sizes; (c)Gradual change in a landscape; (d)Indoor windows between rooms.

taken from the front. The resulting image is used as a background or input image to calculate the open area of the curtains using the background subtraction method.

User interfaces are implemented to extract the screen area. As shown in Figure 3(a), clicking four points on the camera image displayed on the PC, the user can crop the image onto a rectangle. By specifying the four corners of the screen area to be projected, only the screen area is extracted.

3.2.3. Projection using a projector

The system can be used if the entire screen area is included in the projection range of the projector. The image of the window between the curtains, created from the mask image obtained using background subtraction and the original window image, is projected onto the screen area. The projector can be positioned at any desired location provided that sufficient projection distance is maintained.

User interfaces are implemented to project images according to the screen area. First, a black image is projected over the entire projection area. As shown in Figure 3(b), by clicking on the four points in the corners of the screen area while viewing the projected black image. The window image is transformed using projective transformation and displayed inside the rectangle. Thus, the projector's output is projected only onto the screen area.

4. Applications and Other Possibilities

This section describes an example application using the proposed system. The actual appearance of the projection is shown in Figure 1.

The system was implemented in the environment shown in Figure 4(a). In addition to the devices described

earlier, SwitchBot Curtains [11] were installed. The curtains can be operated remotely and automatically at specified times.

The system calculates and projects the open area of the window in real time so that the window always appears between the curtains. The system presents windows in response to the opening and closing of the curtains and to random movement of the curtains in everyday life.

The size of the window can be easily changed because the system uses projection to present the window. The appropriate window can be presented according to the type of curtains, the location where it is projected, and the design. Figure 4(b) shows windows whose sizes change according to the curtains.

4.1. External Window

The system can be used as an external window that serves as a boundary between the inside and the outside. A screen and curtains are installed on the wall facing the outside of the room, and any view can be projected without depending on time or location. The projected images and videos can be changed according to the users' preferences. This system presents a view of the outside regardless of the location of the indoor space or the local time.

Another possible application is projecting a view that changes according to the actual environment. As shown in Figure 4(c), it is possible to present the current time of day or weather to people indoors by gradually changing the projected image.

4.2. Indoor windows between rooms

The system is used to create an indoor window between rooms. Two webcams are used to project other locations in real time.

A screen and curtains are installed on a wall facing another room, and images of the room behind the screen are projected in real time (Figure 4(d)). In this application, a space that is behind a wall and therefore invisible can be viewed without noticing the existence of the wall. For example, when children are in another room, their parents can keep an eye on them by looking in the direction in which they are originally located.

Another possible application is installing two systems on a wall separating adjacent spaces. This allows users in both rooms to see each other. The users can communicate with each other from their own spaces and feel as if they were in the same room.

4.3. Remote communication tools

This work proposes a method that uses curtains as a remote communication tool based on the SmoothCurtain [9]. In the case of the Smooth Curtain, the opening and closing motion of the curtain was used based on its role as a boundary between the inside and outside of a room.

People in remote areas will be able to communicate with each other through windows provided by the system. Taking advantage of curtains as a boundary between the inside and outside of a room, it requests a connection by opening the curtains and ends it by closing the curtains. Since it uses the opening and closing of curtains, which is closely related to privacy management, the communication is more familiar to our daily lives than video calls using PCs or smartphones.

5. Discussion and Limitations

5.1. Evaluation of the system

The system is flexible in terms of space because the camera and projector are not limited in terms of positioning and the size of the window can be changed by adjusting the projection. However, curtains would need to be installed. Furthermore, the effectiveness of the spatial presentation in this study has not been evaluated by actual users. It is necessary to evaluate the system with actual users in terms of effectiveness and implementation costs.

5.2. Limitations associated with using the background subtraction methods

This research uses the background subtraction method to calculate the open area of curtains, and the curtains are detected by comparing the luminance difference between the background image and the input image. Therefore, the area between the open curtains cannot be calculated accurately if the luminances of the two images are similar. It is necessary to use curtains that are not too bright because the color of screen is white.

In addition, there is also the problem of occlusion in daily life. Since there are few restrictions on the position of the camera and projector, there are not many opportunities for occlusion to occur. However, the presence of objects or people in positions that block the direction of the projector and camera will affect the appearance of the window.

5.3. Expansion of functions

Although we have demonstrated several application examples, further work is needed to extend the system's functions to make it easier to use and more effective.

The user can actually touch the curtains, which are commonly used everyday items. This makes the system highly familiar. Furthermore, the system can be extended to behave more like a real window by adding a function that swings the curtains with the wind. Moreover, sounds according to the scenery will provide realistic external information.

If the user want to use a certain image or video of the scenery, they need to manually paste the window frame. Therefore, a tool that automatically creates window frames on images can be implemented to allow users to use their preferred materials to be projected.

We also demonstrated a remote communication tool as an application example. To make the system realistic, it is necessary to add its functionality such as the ability to integrate a video call function and the ability to produce sound.

6. Conclusions

This research developed a system that uses projection to present a virtual window by installing a screen and curtains on a wall. The effectiveness of spatial presentation was demonstrated through examples of applications, such as external windows, indoor windows between rooms, and remote communication tools. In the future, we will conduct user surveys to assess the effectiveness of the system.

Acknowledgments

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